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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

WAR GAS INVESTIGATIONS

[redacted]

ADVANCE CHAPTER FROM BULLETIN 178
WAR WORK OF THE BUREAU OF MINES

BY

VAN. H. MANNING

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CORRECTIONS.

At the end of page 39 add—

At the University of Michigan Dr. M. Gomberg did some valuable work on mustard gas and other toxic-gas syntheses.

On page 38, seventh line from bottom, add—

Dr. James Withrow did especially valuable work on prussic acid, cyanogen chloride, arsenic trichloride, and other substances.

Last three lines on page 20 and first line on page 21 should read—

the life of canisters.

Lieut. J. H. Yoe aided in devising a canister for protection against carbon monoxide. Also, a special canister for protection against hydrocyanic acid was developed by Lieuts. Yoe and Beattie.

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WAR GAS INVESTIGATIONS.

GENERAL STATEMENT.

Of all the war work by the Bureau of Mines none ultimately covered such a variety of processes and equipment, employed as many men, or called for as large an outlay as that started in connection with the solution of problems relating to the use of noxious gases in warfare. Beginning with an investigation to develop the best type of gas mask, the scope of the work extended until it included researches relating to a wide range of devices, such as different types of poisonous and irritating gases and smokes, smoke screens, gas shells and gas bombs, flame throwers, trench projectors for firing gas bombs, signal lights, and incendiary bombs. The Bureau of Mines in starting this work selected the necessary personnel, procured the early equipment, and for some months, from the beginning to June 30, 1917, paid the cost of the work from its own funds.

The Bureau of Mines built up a research staff of more than 700 chemists, including many of the most prominent chemists in the country, and obtained the cooperation of many of the universities and chemical companies. When the results obtained through this research were to be applied by the War Department, the Director of the Bureau of Mines cooperated in the selection of men to have charge of manufacture or further development, recommending chemists who subsequently received commissions in the Army. The personal cooperation with the War Department was thus very close.

The bureau can fairly claim that because it started this work on gas warfare and received the hearty support of the Department of War, the Navy Department, the National Research Council, and State, educational, and private institutions, the country was in July, 1918, months ahead of where it would otherwise have been in the production of gas masks and other devices. The production of toxic gases then far exceeded the supply of shells. In addition the later work in gas-mask manufacture by the Surgeon General's Office of the Army, which resulted in the development of the best mask produced anywhere; in gas manufacture and gas proving-ground tests by the Bureau of Ordnance, and in the chemical warfare program of the Navy, including the use of smoke screens, shells and toxic gases, were the direct results of the bureau's experimental work.

The American charcoal and soda lime, developed through the research work, are the best used by any nation. The Bureau of

Mines was instrumental in developing satisfactory methods of manufacturing chlorpicrin, phosgene, mustard gas, brombenzylcyanide, cyanogen chloride, and other noxious substances on a large scale. The bureau also developed a smoke funnel for the Navy which no doubt saved many ships from submarine attacks, and devised smoke barrages, signal lights, incendiary darts, etc., for the Army. The Ordnance Department of the Army asked for incendiary bombs and were furnished with bombs better than any made previously.

Perhaps the greatest single result of the research work has been the demonstration of the value of the services that the chemist and chemical engineer can render in time of need and the recognition of chemical investigations as a necessary function of the Government.

GENERAL HISTORY OF THE RESEARCH WORK.

INCEPTION OF THE RESEARCH WORK.

In February, 1917, when war between the United States and Germany seemed inevitable, the Bureau of Mines took up the question of what it could do to most advantage in the event of war. Since its establishment in 1910, it has maintained a staff of investigators studying poisonous and explosive gases in mines, the use of self-contained breathing apparatus for exploring mines filled with noxious gases, the treatment of men overcome by gas, and similar problems. At a conference of the director of the bureau with his division chiefs, on February 7, 1917, the matter of national preparedness was discussed, and especially the manner in which the bureau could be of most immediate assistance with its personnel and equipment. One of the things decided was to investigate gas masks and rescue apparatus for military and naval purposes.

On February 8, the director wrote C. D. Walcott, chairman of the military committee of the National Research Council, pointing out that the Bureau of Mines could immediately assist the Navy and the Army in developing for naval or military use special oxygen breathing apparatus similar to that used in mining. He also stated that the bureau could be of aid in testing types of gas masks used on the fighting lines, and had available testing galleries at the Pittsburgh experiment station and an experienced staff which included W. E. Gibbs, the inventor of the Gibbs breathing apparatus. Dr. Walcott replied on February 12 that he was bringing the matter to the attention of the military committee.

On February 7, a request for information regarding the construction of the Gibbs apparatus came from the Brooklyn Navy Yard. At a conference in New York on February 20, Asst. Naval Constructor G. W. Fulton and an assistant, of the Brooklyn Navy Yard, and G. S. Rice, chief mining engineer, and O. P. Hood, chief mechanical engineer of the Bureau of Mines being present, breathing apparatus constructed in the navy yard instrument shop was shown. Then Mr. Gibbs went to the Brooklyn yard to offer his help in designing suitable short-time apparatus, and also to give information he had received from Dr. J. S. Haldane, the English physiologist, when the latter visited the Pittsburgh station in 1916, regarding methods of absorbing CO_2 in the atmosphere of submarines. In addition to the need of developing a short-time apparatus for use on ships, there was also need for a half-hour apparatus for use in mines and for general purposes. Subsequently Mr. Gibbs spent much time working with officials of the Navy Department on problems relating to the use of breathing apparatus and the absorption of CO_2 on submarines.

On February 20, the Naval Consulting Board submitted to the bureau two questions: One related to the development of some substance which on the detonation of a high explosive in a confined space would render innocuous the gases of the explosion; the other related to putting out fires in confined spaces aboard ship. The inquiries were referred to C. E. Munroe, consulting chemist of the bureau; his recommendations were forwarded to the naval board on March 9, 1917.

On April 4 a conference was held at the War College at Washington. At this meeting there were present Gen. Kuhn, then president of the War College; Col. Aultman, of the college; Maj. Williamson, of the Army Medical Corps; Director Manning, Mr. Rice, Dr. Yandell Henderson, Mr. Gibbs, Mr. Burrell, and Mr. Fieldner, of the Bureau of Mines. The conferees discussed what could be done by the Bureau of Mines in testing gas masks and self-contained breathing apparatus for military and naval use. Director Manning stated that he had just received notice that the War and Navy Departments, through the military committee of the National Research Council, had placed the investigation of this matter in the hands of the bureau. Gen. Kuhn agreed that this arrangement was satisfactory, and detailed Maj. Williamson to represent the War College.

On April 5, at a meeting at the office of Director Manning, Maj. Williamson and Messrs. Burrell, Henderson, Fieldner, Gibbs, Cottrell, and Rice being present, Maj. Williamson gave a review of the use of noxious gases for offensive warfare, of the measures taken for protection against them, and of the work being done in England. He said that the gas masks collected by military observers had been sent to the Picatinny Arsenal, and some tests might be made there. Director Manning assigned a gas chemist to assist Maj. Williamson in going over the masks collected by the Army, and on April 6 this work began.

The director offered the supervision of the research on gases to G. A. Burrell, who had been for a number of years in charge of the chemical work done by the bureau in connection with the investigation of mine gases and natural gas. In April, 1917, Mr. Burrell was in commercial work in Pittsburgh. He accepted the offer on April 7.

COMMITTEE ON NOXIOUS GASES, NATIONAL RESEARCH COUNCIL.

The National Research Council was organized to act as an intermediary on research between the scientists and the universities of the country and the various departments of the Government and to suggest and consider research problems.

On April 6, 1917, the Director of the Bureau of Mines informed the Secretary of the Interior of the appointment of a committee on noxious gases, National Research Council. With the approval of the National Research Council and the War and Navy Departments, the following men were designated as members of the committee: Chairman, Van. H. Manning, Director of the Bureau of Mines; Col. E. B. Babbitt, Ordnance Department, United States Army; Lieut. T. S. Wilkinson, Bureau of Ordnance, United States Navy; Maj. L. P. Williamson, Medical Department, United States Navy; Dr. M. T. Bogert, professor of organic chemistry at Columbia University; and Dr. C. L. Alsberg, Chief of the Bureau of Chemistry, Department of Agriculture. On April 12 Lieut. Commander A. H. Marks, Bureau of Construction and Repairs, Navy Department, was designated a member of the committee, and on April 25, Past Asst. Surg. E. F. Dubois, Bureau of Medicine and Surgery, Navy Department.

This committee took up various problems relating to the use of gases in warfare amd made recommendations to the National Research Council, which transmitted those it approved to the organization interested. The membership of the committee changed somewhat from time to time through the transfer of Army and Navy officers; it continued its activities until August, 1918.

After the transfer of the war gas investigations to the War Department in June, 1918, the committee on noxious gases was dissolved on August 10, 1918. The membership of the committee then was as follows: Chairman, Van. H. Manning, Director Bureau of Mines; Passed Asst. Surg. E. F. Dubois, Bureau of Medicine and Surgery, United States Navy; Lieut. Col. R. A. Millikan, Signal Corps, United States Army; G. E. Hale, National Research Council; Lieut. Col. E. J. W. Ragsdale, Ordnance Department, United States Army; Col. Bradley Dewey, Chemical Warfare Service, United States Army; Lieut. Col. M. T. Bogert, Chemical Warfare Service, United States Army; Lieut. Col. E. J. Atkisson, Engineers, United States Army; Lieut. Commander T. S. Wilkinson, Bureau of Ordnance, United States Navy; C. L. Alsberg, Bureau of Chemistry.

DETERMINATION OF RESEARCH PROBLEMS.

As a first step the Bureau of Mines assembled all available reports on the use of gases in warfare that had come to the War or the Navy Department. At that time a little work had been undertaken by the Army in regard to the development of gas masks and the use of smoke screens.

Various lines of research were marked out, that of most immediate importance being the development of gas masks for the Army. This problem required much research on the materials to be used in the masks and much experimenting to develop the various parts. Maj. Williamson cooperated actively in this work, as did Lieut. Commander A. H. Marks, who was vice president of the Goodrich Rubber Co. before offering his services to the Government and was the pioneer in developing a gas mask for the Navy. Having the facilities of the Goodrich Company at his command he took an active part in the new work.

As soon as the chief lines of research had been determined, the next question was the selection of the best available chemists and engineers, many of whom were offering their services to the Government for the conduct of each new line of investigation as it came up.

By June 30, 1917, the personnel engaged in research work comprised 50 paid investigators, and the work had expanded from the devising of gas masks to the study of poison gases and chemical appliances for offensive warfare.

ADVISORY BOARD.

In November, 1917, Secretary Lane appointed the following advisory board to the Director of the Bureau of Mines on war problems: Dr. Wm. H. Nichols, Prof. E. C. Franklin, Dr. C. L. Parsons, Mr. Wm. Hoskins, Prof. H. P. Talbot, Dr. F. P. Venable, Dr. Ira Remsen, and Prof. T. W. Richards.

This board acted in an advisory capacity to the director on the gas work, both individually and as a body. The board first met on December 17, 1917, when it visited the laboratories, consulted with the research staff, and witnessed a demonstration of the work in progress. A second meeting was held May 15 and 16, 1918, when the work was again reviewed.

COOPERATION WITH WAR DEPARTMENT, NAVY DEPARTMENT, AND NATIONAL RESEARCH COUNCIL.

Throughout the course of the war-gas investigations the Bureau of Mines kept in close touch with officials of the War and Navy Department and with the Navy and Army officials of the Council of National Research; these received copies of reports telling of the progress of the work. When some fact had been determined that seemed to have a practical application, officials who would be interested were notified, and they decided whether further study should be given it.

At the American University station, the officers and enlisted men reported to the commanding officer there, who assigned them to work in the laboratories or testing units under the direction of the chiefs of the Bureau of Mines. The supervision of the work was under the director of the bureau, through the assistant in charge of gas investigations. This arrangement worked smoothly, as was testified by the manner in which the reasearch work kept in advance of the large-scale production of the gases, explosives, and devices that were approved.

CHEMICAL SERVICE OF THE NATIONAL ARMY.

One of the early results of the research work undertaken by the Bureau of Mines was the establishment of the chemical service as a unit of the National Army. This unit was established in December, 1917, as a result of conferences held at the Bureau of Mines with officers from the Navy, the Medical Department, the War College, and the General Staff of the Army, and civilian chemists. Lieut. Col. W. H. Walker commanded the American branch of the Chemical Service, reporting to Col. C. L. Potter, of the Gas Warfare Division, and Lieut. Col. R. F. Bacon was chief of the Chemical Service Section in France. Subsequently Lieut. Col. Walker was transferred to the Ordnance Department and put in charge of enormous plants for making chemicals for gas warfare that were erected at a new arsenal, known as Edgewood Arsenal, near Baltimore. His successor in charge of the Chemical Service Section was Lieut. Col. M. T. Bogert.

The establishment of this unit is a noteworthy fact in the history of applied chemistry, for never before in any war or in any country had chemistry been recognized as a separate branch of the military service.

ESTABLISHMENT OF AMERICAN UNIVERSITY EXPERIMENT STATION.

On April 30, 1917, B. F. Leighton, president of the board of trustees of the American University, made a formal tender to President Wilson of the university's buildings and grounds, who referred the offer to the Secretary of War.

On the university grounds were two large stone buildings, the College of History building and Ohio Hall. The grounds were isolated enough to permit the making of field tests and the training of men in gas warfare and yet were readily accessible.

On May 26, 1917, the committee on noxious gases of the National Research Council, Van. H. Manning, chairman, discussed the need of establishing a central laboratory in Washington to coordinate the investigations on noxious gases, and of having work begun on a large scale under the joint cooperation of the Army, the Navy, and the Bureau of Mines of the Department of the Interior. The committee resolved to recommend to the Secretary of War and the Secretary of the Navy that such a research laboratory be established at the American University, the War and Navy Departments to provide funds for equipment and personnel of the laboratory, to be expended by those departments under the direction of the committee on noxious gases. This resolution was approved by the National Research Council and transmitted through the Munitions Board to the Council of National Defense, which referred it to the Secretary of War, the Secretary of the Navy, and the Secretary of the Interior.

On recommendation of Admirals D. W. Taylor and Ralph Earle, of the Bureau of Ordnance of the Navy Department, an allotment of $50,000 for this purpose was authorized by the Secretary of the Navy on June 6, 1917. In a letter to the Secretary of the Interior, under date of June 15, the Director of the Bureau of Mines outlined the cooperative arrangement, stating that preliminary steps had already been taken for installing a central laboratory at the American University, and that the Secretary of the Navy had allotted $50,000 for this work. The arrangement outlined was approved by Secretary Lane. On June 25, 1917, Secretary Baker notified Secretary Lane that he had authorized the expenditure of $125,000 by the War Department for this purpose to be expended under the direction of the Bureau of Mines.

On July 6, 1917, Director Manning wrote the chancellor of the American University, Rev. J. W. Hamilton, accepting the offer of the use of Ohio Hall; the formal grant by the university through the president of the board of trustees was made July 21, 1917. By the terms of the grant the Government was to have the use of the building for two years from June 30, 1917, and as much longer as the war might last, and the Government was not to remove any of the permanent additions made.

The needed changes and improvements were quickly made, and the American University station of the Bureau of Mines came into being. A temporary laboratory building and other structures were completed in September, 1917. Meanwhile the War Department had begun to prepare a camp, named Camp Leach, on the grounds, for accommodating the men assigned to this work and for the training of enlisted men and officers in gas warfare.

By October the need of more room for laboratories and for offices became pressing. The chancellor on October 13 granted the Bureau of Mines permission to use part of the College of History building. Subsequently the bureau occupied nearly the whole of this building in addition to Ohio Hall.

ADDITIONAL ALLOTMENTS OF FUNDS.

To carry on the research necessary for developing the best devices and methods for having them manufactured as soon as possible on a large scale, a considerable increase in personnel and in testing facilities was needed; hence it was clear that more funds was required. When this was brought to the attention of the Navy Department, Secretary Daniels asked that $100,000, from the $100,000,000 appropriation expendable by the direction of the President for national defense, be allotted to the Bureau of Mines for conducting necessary experiments. The President's reply to Secretary Daniels, under date of September 17, follows:

17 SEPTEMBER, 1917.

THE WHITE HOUSE,
Washington.

MY DEAR MR. SECRETARY:

I have your request, sent me under date of September 10, that $100,000 be allotted to the Navy Department from the $100,000,000 appropriation from the national security and defense, to be expended by the Bureau of Mines in the conduct of experiments in the uses of gases in war, in addition to the $50,000 already allotted under date of July 7. I am very glad to make this allotment inasmuch as I realize the critical importance of the investigations referred to.

Cordially and sincerely, yours,

(Signed) WOODROW WILSON.

Hon. JOSEPHUS DANIELS,
Secretary of the Navy.

The rapid expansion of the research work to keep pace with the demands made on it in connection with outfitting the Army and Navy necessitated additional expenditures that could not be foreseen. A new gas might assume extreme importance over night and an expenditure of $50,000 might be required to put it into production. A large number of chemists worked on each important problem to get out results as quickly as possible. The necessary funds were supplied by the War Department and the Navy Department.

The total sum allotted by the Army for war gas investigations during the fiscal year ended June 30, 1918 was $2,212,000; the total sum allotted by the Navy was $250,000.

TRANSFER OF RESEARCH WORK TO WAR DEPARTMENT.

By May, 1918, the question had arisen as to whether the research work on war gases should be transferred to the War Department or should continue under the Bureau of Mines. Certain Army officials believed that the work could be coordinated better by having it under military control. On the other hand it was held that there was nothing to be gained by a transfer of authority as the research work had kept well in advance of the manufacturing development in progress under the War Department and the development of methods of manufacture had been conducted so expeditiously that the supply of toxic materials exceeded the supply of shells. The Advisory Chemical Board said of the work being done by the Bureau of Mines: "The efficiency, success, fine spirit, and enthusiasm under the leadership of the Bureau of Mines is a matter upon which we wish to congratulate the bureau, as well as upon the splendid group of unselfish, self-sacrificing men who carried on this arduous and dangerous work." In regard to the organization of the work the board said: "The organization is complex and delicate but well articulated and working with an efficiency and enthusiasm which have impressed us greatly."

However, the counsel of those Army officers who believed the research work should be transferred to the War Department prevailed, and on June 25, 1918, under the authority given by what is known as the Overman Act, approved May 20, 1918 (Public, No. 152), President Wilson transferred the work being done at the American University from the Bureau of Mines to the Chemical Service of the Army. In letters relating to this transfer, the Secretary of War and the President have expressed their appreciation of the bureau's work, as follows:

JUNE 25, 1918.

MY DEAR MR. PRESIDENT:

In connection with the proposed transfer of the chemical section at American University from the Bureau of Mines to the newly constituted and consolidated Gas Service of the War Department, which you are considering, I am specially concerned to have you know how much the War Department appreciates the splendid services which have been rendered to the country and to the Army by the Department of the Interior, and especially by the Bureau of Mines, under the direction of Dr. Manning. In the early days of preparation and organization Dr. Manning's contact with scientific men throughout the country was indispensably valuable. He was able to summon from the universities and the technical laboratories of the country men of the highest quality and to inspire them with enthusiastic zeal in attacking new and difficult problems which had to be solved with the utmost speed. I do not see how the work could have been better done than he did it, and the present suggestion that the section now pass under the direction and control of the War Department grows out of the fact that the whole subject of gas warfare has assumed a fresh pressure and intensity, and the director of it must have the widest control so as to be able to use the resources at his command in the most effective way possible. The proposal does not involve the disruption of the fine groups of scientific men Dr. Manning has brought together, but merely their transfer to Gen. Sibert's direction.

Respectfully, yours,

NEWTON D. BAKER.

THE PRESIDENT.

---

26 JUNE, 1918.

MY DEAR DR. MANNING:

I have had before me for some days the question presented by the Secretary of War involving the transfer of the chemical section established by you at the American University from the Bureau of Mines to the newly organized Division of Gas Warfare, in which the War Department is now concentrating all the various facilities for offensive and defensive gas operations. I am satisfied that a more efficient organization can be effected by having these various activities under one direction and control, and my hesitation about acting in the matter has grown only out of a reluctance to take away from the Bureau of Mines a piece of work which it thus far has so effectively performed. The Secretary of War has assured me of his own recognition of the splendid work you have been able to do, and I am taking the liberty of inclosing a letter which I have received from him, in order that you may see how fully the War Department recognizes the value of the services.

I am to-day signing the order directing the transfer. I want, however, to express to you my own appreciation of the fine and helpful piece of work which you have done, and to say that this sort of team work by the bureaus outside of the direct war-making agency is one of the cheering and gratifying evidences of the way our official forces are inspired by the presence of a great national task.

Cordially, yours,

WOODROW WILSON.

Dr. VAN. H. MANNING,
Chief, Bureau of Mines, Department of the Interior.

EXECUTIVE ORDER.

It is hereby ordered that the experiment station at American·University, Washington, D. C., which station has been established under the supervision of the Bureau of Mines, Interior Department, for the purpose of making gas investigation for the Army, under authority of appropriations made for the Ordnance and Medical Departments of the Army, together with the personnel thereof, be, and the same is hereby, placed under the control of the War Department for operation under the Director of Gas Service of the Army.

WOODROW WILSON.

25 JUNE, 1918.

With this transfer there passed from under the control of the Director of the Bureau of Mines to that of the Director of the Chemical Warfare Service 1,662 employees who were engaged in the investigations. These employees were classified as follows:

Classification and number of appointees transferred.

	Military.			Civilian.	Grand total.
	Commissioned.	Noncommissioned.	Total.		
Technical	114	596	710	324	1,034
Nontechnical	9	122	131	517	648
Grand total	123	718	841	841	1,682

After the transfer of the research work from the Bureau of Mines, the War Department, on July 1, 1918, combined this work with the large-scale manufacturing gases under the Ordnance Department, Col. W. H. Walker in charge; the gas-mask manufacturing of the Medical Department, Col. Bradley Dewey in charge; the proving ground at Lakehurst, N. J., Lieut. Col. W. S. Bacon in charge; the development division, Col. F. M. Dorsey in charge; and the overseas division, Brig. Gen. Amos A. Fries in charge; and created the Chemical Warfare Service, under the direction of Maj. Gen. W. L. Sibert.

SOME OF THE MORE IMPORTANT FEATURES AND ACCOMPLISHMENTS.

THE FIRST GAS MASKS.

Only the best material is permissible in each and every part of a gas mask. Hence, the rubber companies, in cooperation with the research staff of the bureau, had to work out problems that were entirely new to the rubber industry. Every joint in a mask must be absolutely tight, and the sewing must be perfect. For assembling the various parts of the mask skilled organizations had to be developed out of inexperienced men. The final accomplishment, the best gas mask in existence, testifies to the value of the extensive research work involved in the development of each detail.

About May 1, 1917, the War Department requested the bureau to have manufactured 25,000 gas masks for shipment overseas. Then came a search for makers of cans, buckles, straps, rubber, eyepieces, knapsacks, and other materials who could do acceptable work and do it quickly.

By June 11, 1917, two factories of the American Can Co. in Brooklyn, N. Y., were at work assembling masks. To these factories came the canisters, knapsacks, rubber face pieces, metal parts, eyepieces, anti-dimming compound, instruction cards, repair kits, etc., made elsewhere.

The masks were of the box respirator type, used by the English, the wearer breathing through his mouth and all inhaled air passing through a box or canister containing absorbents. An improvement on the English type was making the charcoal canister larger. The filling absorbent was tested against chlorine, phosgene, and prussic acid, and proved to be highly efficient for absorbing these gases. However, it was not then known that chlorpicrin was to be one of the most important war gases, also that the rubberized cloth for the face piece had to be highly impermeable to gases, and that the soda-lime granules had to be so hard that rough jolting would not produce fines which would clog the canister and make resistance to breathing excessive. Before the end of June 20,086 masks were shipped overseas; another 7,000 were finished during the next two weeks but were never shipped. The masks shipped overseas were tested by the English, who found that they would not give the protection desired against chlorpicrin and other new gases being introduced by the Germans. Subsequently the masks were used in training troops.

This first lot of masks was made and delivered in record time, but owing to the desire of the Army to have manufacturing details directly under its control, the actual manufacture of masks was transferred to the Surgeon General's Office late in July, 1917.

CHARCOAL AND OTHER ABSORBENTS FOR GAS MASKS.

CHARCOAL.

As charcoal had been demonstrated by actual use in masks to be a good gas absorbent, the Bureau of Mines undertook the preparation of a charcoal of maximum efficiency. This search involved much study and experiment. Nearly every chemist in this country who had had special experience in making charcoal was asked for information, and the problem was taken up with concerns making charcoal on a large scale.

At the laboratories of the National Carbon Co. and the National Electric Lamp Works in Cleveland, at the University of Chicago, the Forest Products Laboratory at Madison, Wis., and the Bureau of Chemistry in Washington there were experts on charcoal who were glad to be of service. H. D. Bachelor and M. K. Chaney, of the National Carbon Co. laboratories, and F. M. Dorsey, of the National Electric Lamp Works, and Dr. C. H. Hudson, of the Bureau of Chemistry, Department of Agriculture, were largely responsible for the excellence of the charcoal finally made.

Many different substances were carbonized, and the resulting charcoal tried for a gas-mask absorbent. Different kinds of wood were tried, also nut shells—including coconut shells—lamp black, carbon black, blood, seaweed, and ivory nuts. The first coconut charcoal came from Dr. H. B. Lemon, of the University of Chicago, and by December, 1917, nut shells formed the basis of most of the charcoal used in gas masks.

In preparing highly efficient charcoal the main idea is to clean thoroughly the pores of the charcoal of any hydrocarbon residues, which greatly reduce the absorptive power. One method of cleaning is to let the charcoal cool in air so as to absorb as much oxygen as possible, and then reheat it to a comparatively low temperature. Oxidizing with steam has certain advantages, the charcoal being ground to about 8 to 14 mesh and steam treated.

SODA LIME.

Soda lime, a mixture of caustic soda and calcium hydroxide, is used in gas masks to remove acid vapors or gases from the air. A great deal of study and experiment was given to the making of a suitable product, and by December, 1917, through the efforts of the bureau, a factory, capable of producing 800 pounds a day of this material was actively at work. The soda lime finally produced was much superior to that made by the English.

SODIUM PERMANGANATE.

Sodium permanganate is used in gas masks to oxidize gases or vapors and facilitate their absorption. As the substance was not produced in this country when the work on war gases began, methods of production had to be devised and a supply of the necessary raw material provided. The methods of manufacture devised, when put in operation at a large factory in the fall of 1917, increased the production 50 per cent over methods proposed at the beginning, and gave a much better product.

ABSORBENTS FOR CARBON MONOXIDE.

At the branch laboratory established at Johns Hopkins University Dr. J. C. W. Frazer, formerly a chemist of the bureau, and his assistants, Dr. E. E. Reed, Dr. B. F. Lovelace, and Dr. W. A. Patrick, developed an absorbent in gas masks for carbon monoxide, a problem that had baffled scientists for years. The absorbent is a combination of substances, which largely through catalytic action removes carbon monoxide from air at ordinary temperatures. Twenty grams placed in an Army canister will afford protection against an atmosphere containing 1 per cent of carbon monoxide gas for one hour. This discovery, of high importance in warfare, is also of value in the industries, wherever men may be exposed to an atmosphere containing carbon monoxide. In this work Dr. Frazer was aided by Dr. Bray, of the University of California. In its later phases the work was under the general direction of A. B. Lamb, who in cooperation with C. R. Hoover, of Wesleyan University, also developed an efficient absorbent. Thus a hitherto baffling problem was solved in two ways.

SMOKE SCREENS FOR SHIPS.

One of the problems studied early in the gas investigations was that of devising mixtures for producing smoke screens to hide the movements of troops and to protect ships from attack. The smoke must be intense, heavy and lasting, and a relatively thin layer must completely obscure any object behind it. Also, the smoke cloud must be easily produced and easily controlled, and the materials required for producing the cloud must be readily available, easy to transport, and not dangerous to handle.

A large number of substances were tested by the investigative staff of the bureau. Phosphorus proved the best smoke producer, but it had the disadvantage of being somewhat difficult to control on shipboard. Other substances included titanium tetrachloride, alone and with ammonia; sulphur dioxide and ammonia; zinc dust and carbon tetrachloride; and silicon tetrachloride.

The bureau also studied the best methods of forming smoke clouds. It devised a smoke funnel, in which the chemicals mixed and reacted to form the smoke cloud, and also a smoke box to be dropped from a fleeing ship. In addition the bureau took up the use of poisonous gases in smoke boxes, which would make trouble for the crew of a pursuing ship that charged through a smoke screen.

Under date of July 30, 1917, Secretary Lane called the attention of the United States Shipping Board to these investigations. On August 14, a successful demonstration on board a tug was given.

In mentioning the importance of this research work the Director of the Bureau of Mines said:

> I am informed that the Navy Department has placed an order for about $350,000 worth of smoke mixtures, developed by the research group, to screen merchant ships from submarines. Further, that of 8 ships which were attacked, and which employed the smoke screen to avoid destruction, 6 escaped, while of 100 ships which did not employ smoke screens 75 were torpedoed.

TYPES OF WAR GASES.

The so-called war gases, many of which are liquids at ordinary temperatures and pressures, can be divided into two general classes, (*a*) lethal substances, generally those that kill by asphyxiation, and (*b*) neutralizing substances.

The neutralizing materials are less poisonous but are capable of putting men out of action for shorter or longer periods of time. To this class belong lachrymators (or tear gases), sternutators (or sneezing gases), and eye, lung, and skin irritants, which inflame the eyes, cause severe respiratory distress, and blister the skin.

Absorbent substances like charcoal, soda lime, sodium phenate, hexamethylamine tetramine, caustic soda, zinc oxide, etc., absorb or neutralize such gases as chlorine, phosgene, prussic acid, chlorpicrin, mustard gas, or xylyl bromide, and when used in gas masks protect against finely divided toxic solids such as diphenylchlorarsine; special clothing is needed for protection against skin irritants such as mustard gas.

SELECTION AND PRODUCTION OF NEW GASES AND SMOKES.

In order to be deemed worthy of large-scale manufacture a new gas had to possess some quality or qualities that rendered it decidedly better for military use than its predecessors. It had to have high lethal value, be a powerful lachrymator or a good sternutator, or vesicant, or be more highly penetrative. The materials for its manufacture had to be plentiful and the process of manufacture could not be too difficult.

When a new gas was under investigation the procedure was about as follows: In the laboratories its physical, chemical, and physiological properties were determined, and methods of preparing it were investigated; then a plant for small-scale manufacture was designed. The gas was examined to determine how readily it penetrated American, English, French, and British masks. Also, tests were made to determine the best way of serving it to the enemy, whether in shells or from cylinders. In the meantime a thorough search was made for raw materials for its manufacture. If all investigations proved satisfactory, it was turned over to the Ordnance Department—either to the development division, to build the first large unit, or to the gas manufacturing division. Chemists from the research division, who were familiar with the process of manufacture, were transferred along with the latter when it left the research division.

As soon as the research staff had completed work on some of the more important substances, larger plants were designed for manufacturing the materials in quantities at the Edgewood Arsenal.

In the first program, based on the experience of the English and French and the experiments made by the Bureau of Mines, as set forth in a letter dated July 27, 1917, from the Director of the Bureau of Mines to the Chief of Ordnance, the offense gases selected were, chlorpicrin, phosgene, xylyl bromide, and prussic (hydrocyanic) acid. As none of these substances had been manufactured in this country on a large scale, the technique of such manufacture had to be developed. The Director of the Bureau of Mines recommended manufacture by private concerns at that time, and not at Government plants because of the delay that would necessarily follow. The first large-scale work on chlorpicrin was done at the plant of the American Synthetic Color Co., at Stanford, Mass. The xylyl bromide process was worked out with the Dow Chemical Co. Prussic acid was to be furnished from sodium cyanide made by the Bucher process. A plant for making cyanide was erected later by the Bureau of Mines at Saltsville, Va.

The manufacturing program outlined was started by the research staff, under the direction of Dr. William McPherson, of Ohio University, who was transferred from the research staff to the Ordnance Department early in 1918 when that department began a definite gas-manufacturing program. His successor, W. S. Rowland, chemical engineer with the Stanley Works, of New Britain, Conn., worked out details of the process adopted for manufacturing mustard gas.

Huge plants for making mustard gas, phosgene, and chlorpicrin were built at the Edgewood Arsenal. The Oldbury Electrochemical Co. built a phosgene plant at Niagara Falls. This was under the direction of F. A. Lidbury, who also made tons of phosphorus for the American and the allied Governments.

Phosphorus throughout the war was the banner smoke producer for military purposes. Whether or not the use of gas is abolished in warfare, smokes have a definite place. They can be used in small candles to raise a smoke screen preceding the advance of troops to the attack or in shells in order to block off a part of the enemy's forces. Phosphorus has, by weight, 40 per cent more smoke-screening power than other substances the research chemists could find, but it is used wholly in shells.

As a result of all the experimental research work and the arrangements made to produce gases on a large scale, the United States was in a position at the signing of the armistice, on November 11, 1918, to manufacture poisonous gases in quantity equal to the combined production of France and England.

MUSTARD GAS.

Of all the gases used during the war none equaled mustard gas in military effectiveness. This substance, like some others used, is not a gas, but a liquid, dichloro-ethyl sulphide; it has a boiling point somewhat higher than water and volatilizes readily. It clings to the ground, to trees, or the walls of buildings, and its vapor being much heavier than air sinks into trenches, shell holes, and other depressions. The liquid readily penetrates ordinary clothing, and even leather. It causes burns that appear 4 to 12 hours after exposure and heal slowly. The vapor inflames the eyes, causing temporary blindness, and attacks the throat and bronchial tubes, causing bronchitis or broncho-pneumonia.

For some time after mustard gas was introduced by the Germans the accounts of its effectiveness were contradictory, and reliable reports of its efficacy and the service the enemy was getting from it did not reach this country until about December, 1917.

The first work on the production of the gas in this country was done under the direction of Dr. J. F. Norris in the fall of 1917 in cooperation with the Commercial Research Co. After extensive experimentation the ethylene-sulphur-monochloride reaction was adopted, the problem being solved at practically the same time in England. Thereafter work on the gas proceeded rapidly, and when the armistice was signed a plant with a capacity of 200 tons a day was being erected for its manufacture, under the direction of the War Department, at the Edgewood Arsenal.

The experimental work was conducted in various laboratories—one group worked in the research laboratories at Washington; another at the Dow Chemical Co., under the direction of Dr. A. W. Smith; and still another group at Cleveland, under F. M. Dorsey. The best features of the processes so discovered, with those used by the French and by the English, were incorporated in the Edgewood plant.

DETAILED ACCOUNT OF ORGANIZATION, PROGRESS OF WORK, RESULTS.

The more important features of the war gas work conducted under the Bureau of Mines have been outlined. On account of the scope and manifold character these investigations assumed, and the variety of problems attacked, it is not possible in this report to give more than a brief summary of the organization of the research staff and the individual results achieved by the various groups of workers.

As previously related, the rapid growth and increasing importance of the research work resulted in the establishment of a central station at American University in September, 1917, to coordinate the work and effect an efficient unified organization.

PLAN OF ORGANIZATION.

On September 1, 1917, the war-gas investigations of the bureau were organized as follows:

Head, Van. H. Manning, Director of the Bureau of Mines.

In direct charge, G. A. Burrell, assistant to the director in charge of gas investigations.

Defense problems (including research work relating to gas masks and protective devices), W. K. Lewis.

Chemical research (including analytical methods, gases for shells, smoke clouds and bombs, incendiary bombs, absorbents for gas masks, signal lights and gases for balloons), J. F. Norris.

Medical-science research (including physiological investigations of gas masks, pharmacological gassing experiments on men and on animals, pathological gross and microscopic study of gassed animals, and pathological chemistry of disorders of gassed animals), Yandell Henderson.

Pyrotechnic research (including demonstrations and large-scale investigations of gas shells, smoke clouds, signal lights, incendiary bombs at proving grounds and aboard ships, etc.), George Richter.

Chemical manufacture (covering the manufacture of chemicals, on a semicommercial scale, for demonstration purposes), William McPherson.

Mechanical research (including mechanical details of gas-mask design), H. H. Clark.

Investigations of submarine gases (including the removal of hydrogen, carbon dioxide, and engine gases from the atmosphere within submarines), W. E. Gibbs.

Gas-mask research (including tests of canisters and masks and the efficiency of absorbents), A. C. Fieldner.

Of the investigations relating to the chemical examination of balloon gases and the building of plants for their manufacture, those dealing with helium were subsequently placed in charge of F. G. Cottrell, chief metallurgist of the Bureau of Mines, as related in another chapter of this bulletin.

The branch laboratories and the investigators in charge were as follows:

John Hopkins University, J. W. C. Frazer and E. E. Reid.

Princeton University, G. A. Hulett and F. Neher.

Nela Park, Cleveland, Ohio, H. D. Bachelor and N. K. Cheney.

Harvard University, E. P. Kohler and G. P. Baxter.

Bryn Mawr College, R. F. Brunel.

Ohio State University, C. E. Boord.

Massachusetts Institute of Technology, S. P. Naulliken.

Yale University, F. P. Underhill.

With the expansion of the research work new groups of chemists were organized and the personnel rapidly increased. On June 1, 1918, the organization of the war-gas investigations was as follows:

Head, Van. H. Manning, Director Bureau of Mines.

In direct charge, G. A. Burrell, assistant to the director in charge gas investigations.

Defense problems, W. K. Lewis.

Offense problems, E. P. Kohler.

Physiological and pharmacological problems, Yandell Henderson.

Editorial work and miscellaneous research, W. D. Bancroft.

Chemical research (defense), A. B. Lamb; (offense), J. F. Norris.

Manufacturing development (offense), W. S. Rowland; (defense), W. K. Lewis.

Pyrotechnic research, G. A. Richter.

Mechanical research (Army gas masks), B. B. Fogler; (Navy and miscellaneous), H. H. Clark.

Therapeutic research, F. P. Underhill.

Pharmacological research (offense), E. K. Marshall; (defense), A. S. Lovenhart.

Toxicity tests, M. C. Winternitz.

Dispersoid research, R. C. Tolman.

GAS-MASK RESEARCH.

When investigations relating to gas masks began in March, 1917, A. C. Fieldner, chemist in charge of the chemical laboratories at the Pittsburgh station of the bureau, was placed in charge of methods for testing the efficiency of various absorbents, and of testing canisters, and finished masks. Bradley Dewey, research chemist of the American Tin Plate Co., at Pittsburgh, Pa., entered the service of the bureau on May 7, 1917, to take charge of the development of gas-mask manufacture. On August 1, 1917, he was commissioned a major, in the Surgeon General's Office.' Dr. W. K. Lewis, assistant professor of chemical engineering at the Massachusetts Institute of Technology, who joined the research staff in May, 1917, was placed in charge of the development of absorbents. These two men also took a large part in obtaining the cooperation of chemists at many places in studying special problems connected with the production of a satisfactory gas mask and with other work related to the use of gases in warfare.

TESTING OF ABSORBENTS, CANISTERS, FABRICS, AND FINISHED MASKS.

The work of the gas-mask research division, under Mr. Fieldner, was as follows:

Samples of soda lime, charcoal, and other materials were sent to the Pittsburgh station for test by the new standard methods being devised there.

By April 1, 1917, work had begun on developing analytical methods for testing one new gas against another.

When the Army requested the bureau on May 1 to have manufactured 25,000 masks, so many canisters came to the Pittsburgh station for test that temporary laboratories had to be built. Up to this time attention had been chiefly directed to making tests against chlorine, as this gas was used in the first gas attacks made by the Germans. The chlorine testing machine was devised by Mr. Fieldner and by A. W. Gauger, assistant chemist of the bureau, with the aid of the regular staff of the gas laboratory.

When, by June 1, information came that phosgene, chlorpicrin, and hydrocyanic acid were being used, methods were devised for testing absorbents and canisters against these gases.

On July 1, 1917, the testing of canisters and absorbents was organized into two units; the absorbent testing was placed in charge of G. G. Oberfell, and the canister testing in charge of A. W. Gauger, and later of M. C. Teague.

In the summer of 1917 a section was created to determine the penetrability of fabrics for masks and protective clothing by various gases, with G. St. J. Perrott in charge. Mr. Perrott developed the standard methods for testing fabrics that were used later by the Chemical Warfare Service. By June, 1918, approximately 1,000 fabrics had been tested.

In September, 1917, all the gas-warfare work at Pittsburgh was transferred to the American University station in Washington, and a man-test unit was formed with Capt. J. N. Lawrence in charge, assisted by W. J. Harper. A large number of masks were tested against practically all the war gases then known.

As soon as the methods of testing absorbents, canisters, and mask fabrics were completed and standardized, an extensive investigation was begun, early in November, 1917, to determine the best proportion, fineness, position, etc., of the absorbents in a canister. These tests were made on men and on machines.

As each new gas appeared, methods of analysis and of determining the protection various canisters afforded against it were devised. This work was under the direction of C. V. Smith and, later, of Dr. R. E. Nelson.

One-half per cent of all the canisters manufactured by the Gas Defense Service of the Surgeon General's Office was tested on men and on machines, in order to maintain a high standard of manufacture. Lieut. R. N. Pease had direct charge of the machine testing under Capt. Teague. Early in the spring of 1918, a new man house was completed, having a capacity of more than 100 canister tests a day. About 15,000 canisters of all types were tested on men, including the standard Army types, Navy drum type, and various foreign canisters. A change in the filling of the Navy drum improved its efficiency 100 per cent and made it protective against stannic chloride and similar smokes.

On March 1, 1918, a canister-filling section was formed under charge of Lieut. H. J. Beattie, and equipment was installed.

In mechanical testing of canisters, various machines were tried out until a satisfactory type was devised. Later the volume and rate of breathing of men at rest and at various degrees of work were determined, so that results with a machine would duplicate the results of tests on men under any conditions. The first mechanical tests of this type were made about April 1, 1918, against phosgene. Later machines were built for testing against chlorine, hydrocyanic acid, and chlorpicrin, facilities being provided for testing about 150 canisters a day.

Many filtering materials for removing smoke were tried. Lieut. Perrott first suggested and tested the bag type filter and the use of paper as a smoke filterer. The fabric-testing section conducted a long series of weathering tests of gas-mask fabrics at Washington, D. C., and at Pensacola, Fla. Important problems solved by January 1, 1918, included the development of a satisfactory mustard-gas detector, of an impregnating medium for protective clothing, of a method for renovating cloth contaminated with mustard gas, and the devising of so-called "solid mustard" for accustoming troops to its odor.

At a request from Gen. Pershing, in January, 1918, for a cheap method of impregnating dugout blankets, an eminently satisfactory screen was devised by impregnating an ordinary Army horse blanket with a mixture of mineral and vegetable oils. Lieut. Perrott designed and shipped some impregnating machinery.

In January, 1918, a miscellaneous section was formed at Pittsburgh under Lieut. S. H. Katz, formerly assistant chemist of the Bureau of Mines. Among the problems investigated were the effect of temperature on the absorption of gases by charcoal, detection of gases in the atmosphere of submarines, effect of field conditions on the life of canisters, and protection afforded by canisters against industrial gases. This section cooperated in devising a canister for protection against carbon monoxide, also a special canister to give long life against hydrocyanic acid. A method of determining the course of gas through a canister, known as the "wave-front" method, developed by Lieut. Beattie, was of high value in detecting defects in canister design and filling. In May, 1918, detailed tests were made of the protection afforded by standard canisters against various gas mixtures.

MECHANICAL RESEARCH.

Research on the mechanical problems of gas masks began under W. E. Gibbs, inventor of the Gibbs breathing apparatus, in April, 1917; later the division of mechanical research was organized under H. H. Clark, electrical engineer of the bureau. This division had charge of the machine shop at the American University station and the design of gas masks. In May, 1918, the work was divided, B. B. Fogler taking charge of research relating to the Army masks and H. H. Clark taking charge of the mechanical research work for the Navy and miscellaneous research work. In June, 1918, a new machine shop, measuring 120 by 50 feet and accommodating 50 machinists, was nearly completed at the American University.

At first the principal mechanical problems related to the improvement of different parts of the Army mask for soldiers. Next the Tissot type, designed by the French for artillery service, was studied, and a mask developed to a point where the Gas Defense Service put it into production after making certain modifications. This mask has no mouthpiece or nose clip, and the entering air impinges on the eye pieces and reduces fogging. In collaboration with Dr. J. A. E. Eyster a similar type of mask was developed for the Aviation Service.

In collaboration with the United States Rubber Co. a naval mask that carries the canister on the head was developed which affords protection against both war gases and carbon monoxide. The original Navy mask was modified and standardized in the same manner as the Army respirator.

A horse mask and a trench fan similar to those used by the British were designed and specifications submitted to the Gas Defense Service.

In collaboration with the chemical research division, canisters for absorbing carbon monoxide were developed. One of these was standardized for use with the mask adopted by the Navy. Much experimental work was done in the developing of smoke filters for gas masks and the use of baffles and screens for mask canisters. The baffling increases the capacity of the canister, or permits a considerable decrease in size without reduction of capacity. A small canister giving at least 30 minutes' protection against chlorine was developed for use in submarines; also a special canister for the use of workmen in poison-gas plants.

Special clothing was developed for the use of workmen in poison-gas plants. One type of suit was provided with a helmet and a hose pipe to supply fresh air. Another type of suit had a mask, an oilcloth hood, and one of the special canisters.

Other work included the devising of a mechanism for firing smoke boxes from ships, and miscellaneous tests of mask parts, such as eyepieces, nose clips, valves, etc.

PHYSIOLOGICAL RESEARCH.

On April 4, 1917, Dr. Yandell Henderson, of Yale University, who as consulting physiologist of the Bureau of Mines had investigated the improvement of rescue breathing apparatus and resuscitation from gas poisoning, was put in charge of the physiological, or medical science, research of the war gas investigations. The work under his direction grew and expanded so rapidly that by June, 1918, it included ten sections employing several hundred scientific men. The chiefs of these sections formed a board of which Dr. Henderson was chairman.

ADVICE ON GAS MASKS.

Dr. Henderson acted as technical advisor regarding various features of gas masks, being associated with W. E. Gibbs, and helped in arranging for the manufacture of the first 20,000 masks for the American Expeditionary Forces. During the summer of 1917 Dr. Henderson gave scientific supervision to tests of masks on men in the gas chamber and later, with Mr. Gibbs, studied the possible development of a cloth mask of the French type as a secondary mask for American troops. In October, 1917, he had general direction of an investigation conducted by L. F. Rettger, at Yale University, of the most effective ways of sterilizing masks.

TOXICITY AND GASSING TESTS.

Pending the opening of the central laboratory at the American University, Dr. Henderson organized, in New Haven, in May, 1917, tests with animals to determine the toxicity of gases, and the development of better methods of treating men who had been gassed. Drs. F. P. Underhill, H. G. Barbour, M. C. Winternitz, E. K. Marshall, H. W. Haggard, D. W. Wilson, Samuel Goldschmidt, H. F. Pierce, and others were appointed consulting physiologists or junior physiologists of the Bureau of Mines, and in June, 1917, began work in the Yale buildings and in a temporary laboratory at Yale Field. Methods were developed for the accurate quantitative gassing of animals, a new departure, essential for determining the degree of gassing and the methods of treatment, that the possible cure might have a scientific basis. The essential apparatus was the gassing chamber; the initial features of this were designed by Dr. Henderson, but the apparatus was rapidly improved and developed by Prof. Underhill and Drs. Barbour, Marshall, and Haggard. The results achieved were superior to any obtained abroad up to that time.

REORGANIZATION OF THE MEDICAL SCIENCE WORK.

In October, 1917, the pharmacological and toxicological work was moved to the American University at Washington, where it was organized as the division of pharmacological research. This division was in charge of Dr. Marshall, under the supervision of Dr. Henderson. In November, 1917, the other investigations under Dr. Henderson were organized as follows: Dr. F. P. Underhill was placed in charge of therapeutic investigations, at New Haven; Dr. H. C. Bradley, in charge sanitary supervision at gas factories; Dr. Reid Hunt, in charge toxicological research; Lieut. W. L. Bacon, in charge gas-shell tests. As the work increased it was subdivided, Dr. M. C. Winternitz taking charge of pathological research and Dr. Underhill retaining therapeutic research.

SUPERVISION OF SANITATION CONDITIONS AT POISON-GAS FACTORIES.

In August, 1917, when plans were being made for the large scale manufacture of poison gas, Dr. Henderson recognized the need of careful supervision of sanitation conditions and of measures to prevent poisoning among employees. Accordingly, Dr. H. C. Bradley, of the University of Wisconsin, was put in charge of factory supervision. Dr. Bradley immediately began inspection of chlorine and other plants, and selected and trained inspectors. Thus poisoning among the workmen in the plants was largely reduced. Dr. Bradley also began investigations of the treatment of chronic gas poisoning, being aided by Profs. J. A. E. Eyster and A. S. Lovenhart, and Dr. W. J. Meek, of the University of Wisconsin. These investigations resulted in developing a large experimental laboratory at the university, although Dr. Bradley and Prof. Lovenhart were later moved to Washington.

FIELD TESTS OF GASES.

In August, 1917, when the Ordnance Department stated that large-scale field tests of gases would be necessary and physiological advice on the results obtained would be required, W. S. Bacon was placed in immediate charge of such work by the Bureau of Mines, under the general supervision of Dr. Henderson. Mr. Bacon investigated the various proving grounds to determine their suitability for the tests and developed apparatus for testing the toxicity of gases under field conditions. He was eventually commissioned major in the Army, and developed the large proving ground at Lakehurst, N. J.

INVESTIGATIONS ON SHOCK, ASPHYXIA, HEMORRHAGE, AND CARBON MONOXIDE POISONING.

In England and America scientific men were investigating the problems of shock in wounded soldiers. As the solution seemed to depend largely on a better knowledge of the changes in the blood during the different forms of asphyxia, Dr. Henderson had a section of eight men, under Dr. H. W. Haggard at New Haven, investigate these problems. The results obtained show the nature of the changes that take place and afford new conceptions of their character and proper mode of treatment.

AVIATION INVESTIGATIONS.

In September, 1917, Dr. Henderson was appointed chairman of the medical research board of the Aviation Service. The purpose of this board was to develop methods for testing the ability of aviators to withstand altitude and to devise an apparatus to supply oxygen to aviators ascending to great heights. An allotment of $100,000 was transferred from the Air Service to the Bureau of Mines for these purposes.

OXYGEN APPARATUS FOR AVIATORS.

W. E. Gibbs, mechanical engineer of the Bureau of Mines, was assigned to develop the oxygen apparatus. Mr. Gibbs, with the aid of Dr. Henderson, developed an apparatus that can be manufactured on a large scale and is markedly superior to the British type. This apparatus was ready for acceptance when the armistice was signed.

TESTS FOR AVIATORS.

In developing tests for aviators, Dr. Henderson began work at the American University experiment station, and put Prof. E. C. Schneider in immediate charge of the physiological research, and Prof. Knight Dunlap in charge of the psychological research. Dr. Henderson devised for these tests the so-called rebreathing apparatus; this has a tank containing air, which the subject inhales through a mouthpiece and tubing, the exhaled air passing back through a cartridge of alkali which removes the carbon dioxide. As the subject breathes, the oxygen content of the air in the tank becomes progressively lower and his physiologic condition becomes equivalent to that of altitude. Some results of the tests are discussed in seven papers, published in the Journal of the American Medical Association by Dr. Henderson and his colleagues.[a] These tests developed the fact that 14 to 15 per cent of the candidates for the Air Service who passed the ordinary medical examination were really unfit to fly at the altitude necessary for active service, but a small group, between 5 and 10 per cent of the total number, can be picked who are capable of ascending to the greatest altitudes without collapse.

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[a] Organization and objects of the Medical Research Board, Air Service U. S. Army, by Yandell Henderson, and E. G. Seibert; Physiologic observations and methods, by E. C. Schneider; Cardiovascular observations, by J. L. Whitney; Psychologic observations and methods, by Knight Dunlap; The effect of altitude on ocular functions, by W. H. Wilmer and Conrad Berens, jr.; Influence of altitude on the hearing and the motion-sensing apparatus of the ear, by E. R. Lewis; Effects of low oxygen pressure on the personality of the aviator, by Stewart Paton. 1918. Jour. Am. Med. Assoc., vol. 71, Oct. 26, pp. 1382–1400.

In January, 1918, a laboratory was established at the flying field at Mineola, Long Island, for investigative research and for training medical officers to fit them to take charge of similar laboratories at the other flying fields. When the armistice was signed nearly 20 subsidiary laboratories had been established or planned, and a party headed by Col. W. H. Wilmer had been sent to France to establish similar laboratories at the American aerodromes there.

THERAPEUTIC RESEARCH.

Research to determine the changes that take place in the body as the result of exposure to lethal gases, and thus to devise methods of treatment for gas poisoning was organized under Dr. Henderson at Yale University in May, 1917, with Dr. F. P. Underhill in charge. After the pharmacological and toxicological research work was moved to the American University station, therapeutic work was continued under Dr. Underhill, in the laboratories at Yale. Ultimately some 50 men were busy there making examinations of gassed animals, and studying the effects and the treatment of gas poisoning. The work involved the application of chemical methods to physiological processes. The first gas considered was chlorine. By January, 1918, a promising method of treatment for chlorine poisoning was devised. Dr. D. W. Wilson and Dr. Samuel Goldschmidt received commissions in the Army and went to England, where they did further work on phosgene poisoning, finally winning the British authorities over to recognize the fundamental correctness of the method of treatment developed by the work at New Haven. An intensive study of phosgene was made at New Haven, and by July, 1918, a method of treatment had been evolved, which was later indorsed by the Medical Department of the Army. Later it was shown that chlorine, phosgene, and chlorpicrin act fundamentally alike.

Another investigation was undertaken to determine whether inhalation of oxygen would reduce the mortality among persons who had breathed poison gas; another demonstrated that many persons who survive gassing subsequently contract pneumonia or other pulmonary diseases through self-infection with bacteria.

PATHOLOGICAL RESEARCH.

For studying the organs and tissues of animals killed in gassing tests, a pathological section under the general supervision of Dr. Henderson and in charge of Dr. M. C. Winternitz was established in the summer of 1917 with laboratories at the American University station and at Yale University.

The pathological division was established at the American University station under Dr. Winternitz in May, 1918. Prior to that date pathological tests at the station had been made by Dr. G. M. McKenzie.

Among the problems attacked by this division was the effect of mustard gas on the mucous membrane of the eyes and respiratory organs and on the skin. No specific remedy for mustard-gas burns was found, although it was demonstrated that burns could be prevented by washing and scrubbing the skin with kerosene a few minutes after exposure. Mustard gas was shown to be highly toxic.

Tests to determine the minimum effective concentration showed that 1 part of mustard gas in 12,500,000 parts of air would make a soldier a casualty in a few hours, chiefly through inflammation of the eyes.

PHARMACOLOGICAL RESEARCH.

The pharmacological division was established at American University on November 27, 1917, with Dr. E. K. Marshall, jr., in charge.

In May, 1918, the need of determining the toxic value of new gases, the best methods of treating gassed persons, and determining the susceptibility of different individuals led to the enlargement of the toxicologic work. Dr. Marshall was commissioned a captain in the Medical Reserve Corps of the Army and put in charge of the pharmacological research division, which took up all pharmacological problems relating to defense, and Dr. A. S. Lovenhart, of the University of Wisconsin, took charge of the pharmacological and toxicological division which studied offense problems.

On July 1, 1918, the pharmacological research division became the pharmacological research section of the Chemical Warfare Service.

The work of the pharmacological research division comprised the following investigations:

1. Devising toxicity tests by exposing mice, guinea pigs, rats, rabbits, cats, and dogs to poison gases, and by studying the pharmacological and toxicological effects.
2. Testing tear gases and sneezing gases on men.
3. Determining the skin-irritant effect of gases.
4. Testing fabrics for their permeability to mustard gas.
5. Devising analytical methods for the control of the concentration of the gases used in tests.
6. Determining the sensitivity to gas of the skin of different individuals.

Toxicity tests with animals covered a long list of poisonous liquids and vapors. Many of the tests with dogs were for varying lengths of time to determine the relation between the lethal effect and the concentration and length of exposure. Tests were also made with animals in a bomb pit at the American University station and at the Indianhead Proving Ground to determine the effective area of shells charged with the different toxic substances.

A large number of fabrics were tested for permeability to mustard gas, both dogs and men being used in the tests, and results of the tests were transmitted to the Army and Navy.

Many tests with men and animals were made to determine the effectiveness of tear gases and the minimum concentration at which these gases could be detected by their odor or their irritating effects. One result of these tests was to show that man was more than one thousand times as susceptible to tear gas (xylyl bromide) as the horse, and more than ten times as sensitive as the dog.

TOXICOLOGICAL RESEARCH.

Toxicity tests on dogs and experiments to devise a rational method of treating gassed animals were begun by Dr. Henderson at Yale University in May, 1917. These investigations were afterward supervised by Dr. H. G. Barbour and later by Dr. F. P. Underhill.

Preliminary tests were made chiefly with mice. Most of the early work was on chlorine; later, tests were made with chlorpicrin, superpalite, and cyanogen bromide. The analytical control of the toxicity tests was done by L. L. Satler. The lethal values determined for various substances in the early experiments were confirmed by later work in this country and abroad.

In September, 1917, the apparatus accumulated was transferred to Dr. Underhill's laboratory at Yale. Dr. Marshall, as chief of the pharmacological section, went to the American University and took with him Dr. A. C. Kolls, Messrs. L. L. Satler, H. A. Kuhn, and Harry Pettingill. At American University the section was rapidly enlarged.

In November, 1917, F. W. Sherwood and T. W. Snyder, under the direction of Dr. Marshall, took up the determination of the least detectable concentration of poison gases. The section also tested the skin irritant effect of gases, especially mustard gas and the homologues of mustard gas, then that of the chlorine compounds, and then that of the arsenicals, Dr. R. P. Gilbert being assigned to these tests.

At the station as many as 700 dogs were kept at one time. Besides dogs and mice, rats, rabbits, and guinea pigs were used.

In February, 1918, a series of tests in cooperation with the pyrotechnic division of certain toxic shell fillers were made at the American University grounds and at the Indianhead testing ground. Pharmacological work on mustard gas showing its absorption by the lungs and the systemic action of the gas was done by Vernon Lynch.

In May, 1918, Dr. A. S. Lovenhart, of the University of Wisconsin, was placed in charge of pharmacological problems relating to offense, Capt. Marshall retaining those relating to defense. Messrs. A. C. Kolls, L. L. Satler, H. A. Kuhn, and others were transferred to Dr. Lovenhart's division.

GASES IN SUBMARINES.

In February, 1917, W. E. Gibbs, engineer of the Bureau of Mines and inventor of the Gibbs breathing apparatus, was authorized by the director of the bureau to offer the Navy Department the results of experiments with soda lime as an absorber of carbon dioxide, because of its possible use in submarines. A few days later Mr. Gibbs conferred with Naval Constructor Wright and Lieut. G. C. Fuller at the Brooklyn Navy Yard.

Details having been arranged, Mr. Gibbs had made early in March, at the navy yard, about 500 pounds of soda lime, after the formula given him in September, 1916, by Dr. J. S. Haldane of England. At about the same time an apparatus was built at the Navy yard for making use of this soda lime in submarines. In this apparatus a blower circulated the air of the submarine through trays of soda lime contained in a large box.

After experiments at the navy yard, the first long submergence with this apparatus began at New London on June 16, when submarine *G–1* remained submerged for 39 hours. A few days later the same boat remained submerged for 30 hours. A short time after the same boat remained submerged for 48 hours, the air within the boat being as pure at the end of the test as at the beginning. The test was concluded at the end of 48 hours, not because the capacity of the soda lime had been exhausted, but because the supply of food gave out.

After these tests, Lieut. Commander Yates Sterling, then in command of the submarine base at New London, officially reported that these were record submergences for the United States Navy. The longest previous submergence had been 12 hours.

In these tests at the navy yard the soda lime was in tin cartridges containing 50 pounds each. After opening the top and bottom of a cartridge it could be placed directly over the outlet of a small electrically driven blower. The exhausted cartridges were thrown overboard. These cartridges were easily stowed and eliminated the handling of soda lime in bulk.

By September 15, when Mr. Gibbs gave up further work on this problem in order to undertake problems of supplying oxygen to aviators, he was informed that 72 submarines had been equipped with this system. Later, under Dr. Eugene F. Dubois of the Navy, the soda lime was improved in porosity, but the final and best form was that developed at the American University station of the Bureau of Mines.

As elimination of hydrogen from the atmosphere of submarines was necessary to the safety of the crews, Mr. Gibbs had J. F. Duggar, jr., a gas chemist of the Bureau of Mines, attack this problem, which was solved with much ingenuity.

In the 48-hour submergence, Mr. Duggar's apparatus, used for the first time in its improved form, kept the hydrogen down to a negligible quantity. The naval committee in charge of the submergence did not, however, officially report on this performance, because the trial was regarded as a private test and part of the research.

Later, after Mr. Duggar had resigned from the bureau, Mr. Gibbs turned over the data to Dr. E. F. Dubois, who perfected the device.

Early in the spring of 1917 Mr. Gibbs helped in the development of a half-hour breathing apparatus, which was being worked out by John Lind, of the hull division of the Brooklyn Navy Yard.

In September, 1917, Mr. Gibbs was detailed by the bureau to work in cooperation with Dr. Yandell Henderson on the problem of supplying oxygen to aviators when at great altitudes. Shortly thereafter Mr. Gibbs was made a member of the board of medical research on the Aviation Section of the Signal Corps, and until the signing of the armistice was engaged in devising a suitable mask for aviators.

PYROTECHNIC RESEARCH.

The pyrotechnic division was organized in June, 1917. G. A. Richter, formerly chemical engineer of the Berlin Mills Co., of Berlin Mills, N. H., was in charge of the division from the start.

GAS-SHELL SECTION.

Among the tasks undertaken was the determining of the stability of various gases and toxic solids when used in shells. This section also devised a training bomb for use by the gas-defense officers in cantonments, and studied lachrymatory bombs, smoke bombs, and so-called "noise" bombs. Also, several gas-producing chemical combinations were submitted to the Bureau of Ordnance of the Navy for use in armor-piercing shell.

SMOKE-SCREEN SECTION.

The smoke-screen section prepared specifications for a Navy smoke funnel which was accepted by the Bureau of Ordnance. Several hundred of these funnels, made by that bureau, were being supplied to the merchant marine in May, 1918. A smoke-box float was designed and accepted by the Navy; large-scale production had begun in May, 1918. The section perfected a smoke signal for airplane bombs that was accepted by the Ordnance Department, also a similar device for use in the Navy dummy airplane bomb. A portable smoke apparatus using silicon tetrachloride was designed for the Army, a smoke mixture of phosphorus and TNT, for use in shells and in candles, a smoke bomb of the Liven's type, a smoke grenade, and a "noiseless" nozzle for gas attacks. A method of using oleum (fuming sulphuric acid) to produce a smoke screen was accepted by the Navy.

MUNITIONS AND ORDNANCE.

A new form of Stokes mortar was designed that gave greater accuracy and longer range. A long series of tests with Liven's projectors and projectiles were made to reduce the weight of the unit and to increase the range. Results were submitted to the Ordnance Department.

HAND-GRENADE SECTION.

The hand-grenade section was organized at the American University station on October 1, 1917, to continue work on grenades, but as the grenades already adopted by the Army were standardized, the section took up the testing of explosives used in pyrotechny and in gas warfare, and later, testing of high explosives. The sensitivity in use of various picrates was studied in order to assure proper safety measures in storing and handling being taken at the plant making chlorpicrin, for the Ordnance Department; the recommendations were adopted at the plant. Fragmentation tests were made of hand grenades charged with TNT, amatol, and victorite, the last a chlorate explosive; the results were forwarded to the Army and the Navy. Preliminary studies were made of the properties and usefulness of parazol and other chlornitro products as explosives. Studies of chlorate and perchlorate explosives led to the finding of satisfactory chlorate and perchlorate powders for use in hand grenades. A new explosive called anilite, which employs liquid NO_2 as an oxidizing agent, and is used by the French, was studied.

After July 1, 1918, the section was designated the explosives section of the Chemical Warfare Service.

INCENDIARY SECTION.

The incendiary section was organized as a separate unit in October, 1917, under Lieut. A. B. Ray. This section as stated on page 32, originated under the chemical research division (offense), being transferred to the pyrotechnic division in April, 1918.

This section perfected a scatter type of bomb for the Army and an intensive type of bomb for the Army, devised an incendiary dart to be used from air planes, an incendiary projectile for use with the Liven's gun, and prepared recommendations for the Signal Corps as to the best type of explosives to be used with an airplane destroyer.

After July 1, 1918, the section was reorganized as the inorganic section of the Chemical Warfare Service.

FLAMING-LIQUID SECTION.

Two portable flaming-liquid guns were designed and perfected. Tests to determine fuel mixtures for use in connection with the flaming-liquid guns were made and recommendations submitted to the Ordnance Department of the Army.

SIGNAL-LIGHT SECTION.

The signal section conducted a thorough investigation of green flares, devised several colored smokes for use in connection with land signals and air signals, studied methods of improving the white flare, designed an illumination float to be dropped from an airplane, and constructed a special device to be used by submarines in signaling to surface craft.

LABORATORY SECTION.

Linings, packings, and cements for gas shell were carefully studied. A shell that uses a special type of lead lining was recommended to the Ordnance Department of the Army. Further work toward the development of enamel linings and glass linings was under way in June, 1918. Other work included the development of a systematic method for analyzing pyrotechnic materials, and a thorough laboratory study of the usefulness of paper and pulp containers for powder. The recommendations submitted were adopted by the Ordnance Department, which had the tubes made in large quantities by June, 1918.

MISCELLANEOUS SECTION.

This section designed a smoke shell for the Navy, tested a special shrapnel shell with special loading for the Chemical Service of the Army, and made tests of silicon tetrachloride, stannic tetrachloride, and titanium tetrachloride for smoke grenades, to determine which smoke is the most obnoxious.

CHEMICAL RESEARCH (OFFENSE).

The chemical research division, when first established in June, 1917, was in charge of J. F. Norris, with W. K. Lewis as assistant. In October, 1917, the work was divided; A. B. Lamb was placed in charge of problems relating to defense, and J. F. Norris of those relating to offense, also certain problems were turned over to the divisions of pyrotechnic research and manufacturing development. Early in June, 1918, when Dr. Norris received a commission as lieutenant colonel in the Army and went to England, L. W. Jones was put in charge of the offense chemical research work. The problems studied by the division up to May, 1918, were as follows: Preparing new toxic substances; developing the manufacture of toxic materials; development of smoke mixtures and incendiary mixtures; research work on inorganic compounds; and analytical research.

PREPARATION OF NEW TOXIC MATERIALS.

By June 1, 1918, more than 250 toxic substances had been prepared and submitted to the division of pharmacological research for toxicity tests. Many proved promising, but because of the inadvisability of abandoning materials already known to be excellent, comparatively few were recommended. In addition, a number of toxic solids were prepared and delivered to the dispersoid division.

DEVELOPMENT WORK FOR THE MANUFACTURE OF TOXIC MATERIALS.

The section in charge of the development of the manufacture of new toxic materials, later designated organic research section No. 1, came into being in September, 1917, with J. B. Conant in charge.

As almost none of the toxic materials used in modern warfare were being manufactured in the United States, development of manufacturing methods received chief attention up to the end of June, 1918. Investigations, on a laboratory scale, of manufacturing methods for seven toxic substances, including acrolein, martonite, and mustard gas, had been completed in May, 1918.

Practically nothing was known of the manufacture of mustard gas, and many laboratory experiments had to be made to determine details of preparation, purification, and manufacture. By June 1, 1918, most of the experimental work on preparation had been completed and semilarge-scale manufacture had started. As a result of this research, manufacturing was planned by the ethylenechlorhydrin synthesis, which was to be used for the Ordnance Department of the Army at a plant in Flushing, Long Island, and by the sulphur tmonochloride-ethylene synthesis which was used later in the plant a Edgewood Arsenal. Most of the work on mustard gas was under the direction of J. B. Conant. Among those who worked with him were E. B. Harlstrom, G. O. Richardson, and others. W. E. Lewis developed a new gas more effective than mustard gas.

Methods of making important arsenic derivatives were developed. Diphenyl chlorarsine was made in large quantities in the laboratories for the general use of the American University experiment station, as the material could not be obtained elsewhere.

PROBLEMS IN INORGANIC CHEMISTRY.

An incendiary section was organized in October, 1917, under A. B. Ray. This section did early work on flaming mixtures and on incendiary bombs of the scatter type and the intensive type. Incendiary materials were developed for bombs, shells, and projectiles, and for hand darts and grenades. Each of these devices required special incendiary materials, which were adopted by the Ordnance Department of the Army.

The section was reorganized under Lieut. Ray as the section of inorganic chemical research in April, 1918, when it turned over its remaining incendiary problems to the pyrotechnic division.

This section, in cooperation with the pyrotechnic division, prepared specifications for smoke mixtures which were adopted by the Navy for its smoke screens. The section also studied the production of arsine, of calcium and magnesium arsenide, of hydrofluoric acid and fluorides, and of nitrogen tetroxide, the last for use in the new explosive, anilite, devised by the French. The section also studied such toxic materials as cyanides, the selenides and tellurides of arsine, and cyanogen sulphide.

Colored rockets for day signaling were developed and recommended to the Ordnance Bureau of the Navy. The Ordnance Department of the Army adopted the specifications for red and yellow smokes. The smokes prepared were far superior to any then in use in intensity of color and in volume. In February, 1918, the work on colored smokes was turned over to the pyrotechnic division.

Through the work of Lieut. Ray and John Gore the mixtures for use in smoke boxes for the Army were greatly improved.

A suitable resistant enamel for lining shells charged with corrosive substances was devised and turned over to the pyrotechnic division to incorporate in shell design.

ANALYTICAL RESEARCH.

The analytical research section devised new methods of analyzing various materials as they came into use in gas warfare. A matter that received much study was the analysis of gases from the explosion of a gas shell in order to determine whether the toxic material used was decomposed by the explosion. In May, 1918, the section was in charge of Albert Finck.

CHEMICAL RESEARCH (DEFENSE).

When the division of defense chemical research was organized in January, 1918, under A. B. Lamb, it took over problems relating to gas masks, such as the absorbent qualities of the charcoal and the chemicals used, the dimming of eyepieces, the penetrability by war gases of gas-mask fabrics, the development of special absorbents or filters for such irritating or toxic substances as diphenylchlorarsine, carbon monoxide, ammonia, hydrofluoric acid, and cyanogen chloride, and also problems bearing on the detection and neutralization of gases and the production of smoke screens.

The work on the absorbents used in the canisters of gas masks included studies of the effectiveness of charcoal under different conditions, the effect of moisture, aging, etc., by G. A. Hulett at Princeton University and N. K. Chaney at Cleveland, Ohio, and D. W. Wilson. One result of the investigation was the development of an impregnated charcoal superior to any in use abroad. It was subsequently manufactured at a plant in Astoria, N. Y. Investigations of the improvement of the efficiency of soda-lime-permanganate by R. E. Wilson, T. W. B. Welsh, and C. P. McNeil comprised studies of the effect of the size of the grains of this absorbent, the use of cement in obtaining grains of proper hardness, and various problems bearing on the production and use of sodium permanganate and of calcium permanganate.

A carbon monoxide absorbent composed of various metallic oxides was developed by J. C. W. Fraser, J. S. Chamberlain, and others. The absorption of various gases by the canister material was studied by R. E. Wilson, E. W. Fuller, and others.

Ammonia absorbents for use in a Navy mask were investigated by Leo Finkelstein; arsine absorbents were studied by C. C. Scallione and others; paper and other filters for removing diphenylchlorarsine were investigated by R. E. Wilson, F. S. Pratt, and others.

Protective ointments for use against mustard gas and methods of neutralizing mustard gas on the ground were investigated by R. E. Wilson and E. W. Fuller.

In the study of the dimming of the eyepieces of gas masks and the devising of efficient antidimmer compounds much work was done by P. W. Carleton and others. The antidimming compounds were prepared by different manufacturers, or made in the laboratories at the American University. The work on smoke screens included investigations of different types of smoke boxes and the study of smoke-box mixtures by R. E. Wilson, R. H. Ryerson, and others.

MANUFACTURING DEVELOPMENT (OFFENSE).

Research work relating to the manufacture of poison gas was begun by the division of chemical manufacture under Dr. William McPherson, formerly dean of the chemical department at Ohio University, in August, 1917. In December, 1917, Dr. McPherson was transferred to large-scale manufacture, and the division of small-scale chemical manufacture was organized under W. S. Rowland. Later, in January, 1918, the work was again reorganized, Dr. Rowland taking charge of that for defense. The work of the division was aided by the cooperation of the chemical research (offense) division, at first under J. F. Norris and later under L. W. Jones. The results of the chief problems that fell to the offense division up to the end of June, 1918, may be divided into four parts as follows: (1) Determining the most suitable method of production on a large scale; (2) production of gases for testing purposes; (3) production and purchase of chemicals not readily obtainable; (4) storage and shipment of toxic chemicals produced at the American University Station and branch laboratories.

Provisional apparatus, specifications and operating directions for making mustard gas were prepared. Work on other methods was done at Hastings-on-Hudson, N. Y., Cleveland, Ohio, and Midland, Mich. Among the men who worked on mustard gas were L. G. Wesson and E. D. Streeter. Work on manufacturing development of mustard gas was discontinued at the American University in May, 1918.

A small-scale plant for making hydrocyanic acid was put into successful operation.

A group of men in charge of R. H. Uhlinger built a small-scale plant to make superpalite.

In cooperation with the division of chemical research, a small-scale plant was put in operation to make cyanogen chloride. Dr. J. R. Withrow and Dr. E. J. Witzemann worked on this problem.

A small-scale plant for making brombenzyl cyanide was tried out and a large-scale plant designed. This work was done by E. M. Hayden.

In May, 1918, a ton of such mixtures was made up and shipped. More than 500 pounds of magnesium arsenide was made for field tests by June, 1918.

Among the other chemicals made in small lots by this division up to June, 1918, were strontium chlorate, strontium permanganate, nitrogen peroxide, aluminum arsenide, ammonium cyanide, arsenic trichloride, and arsenic trifluoride.

MANUFACTURING DEVELOPMENT (DEFENSE).

When the division of small-scale chemical manufacture was reorganized in January, 1918, W. K. Lewis took charge of the work relating to defense. The results of the principal problems attacked by this division are given below:

A horse mask for the Army was developed that was radically different from the British mask and more efficient.

Work on the production of hydrogen for balloons involved the supervision, construction, and testing of a hydrogen plant for the Army at Langley Field; the control of the raw materials; and the installation of a laboratory equipment.

The division developed testing methods for mustard gas, including tests of absorbent materials such as charcoal, and of protective fabrics. Suitable clothing, including gloves, were developed for protection against mustard gas, and the results turned over to the Gas Defense Service of the Army. A large number of materials were tested for the Gas Defense Service, the work being done in cooperation with the Gas Defense Service and the mechanical development division. The testing methods developed were adopted by the Gas Defense Service.

Members of the division assisted the Gas Defense Service in solving difficulties in the production of absorbent charcoal at Astoria, N. Y., and in the manufacture of "batchite" at Springfield, Mass.

In cooperation with the mechanical development division, an exhaustive study was made of filter materials, such as paper and felt, for gas masks.

Much analytical work was done in the attempt to determine the effect of baffling on the absorption of toxic gas by the canister filling materials.

A new method of investigating toluol, benzol, and xylol in the presence of each other was studied, and fairly quantitative methods for the hydrolysis of the sulphonic acids were developed. These methods promised to be of great value.

In May, 1918, a subdivision was organized to provide satisfactory gas masks for industrial use. Several industries manufacturing poisonous gases for war were supplied with these masks.

DISPERSOID DIVISION.

The dispersoid division was established April 1, 1918, to study the small-scale production of smokes or mists and the best way of protecting men against them, R. C. Tolman being in charge.

Facilities for analytical work with toxic and nontoxic smoke materials, and a dark room for testing the apparatus for optical analyses were provided through the Catholic University, Washington, D. C.

Among the apparatus developed was a Tyndall meter for determining the rate of dissipation of smokes under varying conditions. Tests were started to obtain systematic data on the toxicity and rate of dissipation of smokes, and rate of penetration through filters and mask canisters. One of the problems taken up was the development of smoke candles.

Besides the work on smokes, the dispersoid division continued some of the work on primers that was started at Urbana, Ill., using the Tolman hangfire measurer. Routine tests of airplane ammunition were made with this machine for the Ordnance Department.

EDITORIAL WORK AND MISCELLANEOUS RESEARCH.

In October, 1917, Dr. Wilder D. Bancroft, professor of physical chemistry at Cornell University, joined the gas research staff of the Bureau of Mines. At first he helped keep the various branch laboratories in touch with the Washington laboratory, and later organized a staff which edited and scrutinized all reports leaving the American University station. Dr. Bancroft also had charge of a group of chemists that worked on various problems.

WORK AT THE CARNEGIE INSTITUTE OF TECHNOLOGY.

Work in the war-gas research laboratory at the Carnegie Institute of Technology at Pittsburgh, Pa., began about June 20, 1917, under the general direction of Dr. W. K. Lewis, and the immediate supervision of Dr. R. E. Wilson, formerly assistant professor of chemistry at the Massachusetts Institute of Technology. The work was transferred to Washington about September 15, 1917.

Four main problems engaged the attention of this laboratory: The development of soda lime, the production of smoke screens, the removal of CO from the air in submarines, and the development of incendiary bombs.

In the work on soda lime, a study was made of the effect of different processes of manufacture on the composition and physical properties of the product, as related to its absorptive capacity for various war gases, and stability in use. As a result it was possible, on September 1, to improve greatly the method of manufacture being used by the Army. This investigation also served as a groundwork for further research, which eventually resulted in the development of the best soda lime used by any nation. This work was chiefly done by Dr. P. W. Carleton and Dr. C. P. McNeil.

In the work on smoke screens, substances for producing smokes for screening ships from submarines were studied. Silicon tetrachloride and ammonia were recommended, also a method of production on a large scale. The apparatus devised was developed further at the American University station and placed on practically all ships about December, 1917. The general principles developed in smokes proved of great value later in connection with the work on toxic gases. Paul G. Woodward worked on this problem.

A method of absorbing CO from the air of submarines by ozone in the presence of a catalytic agent was found to be effective, but the size of the necessary ozone generating unit prohibited its use. Dr. F. H. Smyth and Dr. A. B. Ray were engaged upon this problem.

An incendiary bomb for airplanes was designed that gave good results; it was considerably improved later by the incendiary section at the American University station. Dr. A. B. Ray did most of the work.

The laboratory also contributed to the solution of several minor problems, including the development of methods of testing absorbents against superpalite and phosgene, the improvement of antidimming compounds for gas-mask eyepieces, the testing of eyepieces, preliminary work on the impregnation of charcoal, development of signal smokes, etc. This work was done largely by W. D. Wolfe and E. W. Fuller.

Not the least important work of this early laboratory was the development of a trained personnel. Messrs. Smyth, Ray, Carleton, McNeil, Woodward, and Wilson were later all placed in charge of investigations at Washington or elsewhere.

WORK AT CATHOLIC UNIVERSITY AT WASHINGTON.

One of the largest of the branch laboratories engaged in the study of war gases was that of the Catholic University at Washington. The work done there included the study of various problems in organic chemistry under the direction of Dr. W. K. Lewis; investigations of smokes and mists (dispersoids) under Dr. R. C. Tolman; and the study of various problems of physical chemistry under Dr. W. D. Bancroft, including catalytic investigations, such as the catalytic action of charcoal, the production of fluorine and fluorine compounds, the conversion of phosgene into superpalite, and the oxidation of alcohol to acetic acid. At the time of the transfer of the research work to the War Department, June 27, 1918, there were about 75 persons, civilians and enlisted men, busy at the Catholic University.

Dr. J. J. Griffin, the head of the chemical department of the university, greatly facilitated the investigations by his work and cooperation.

WORK AT OTHER UNIVERSITIES.

At Clark University Dr. C. A. Kraus worked on the dimming of eyepieces of gas masks; on metal Dewar flasks for providing liquid oxygen for aviators and submarines; on the stability of gases; on a heat interchanger for use on submarines; and on boosters for gas shells.

At Yale University Dr. T. B. Johnston had charge of a staff of organic chemists that worked chiefly on the halogen ethers, on hydrogen selenide, and on certain selenocyanides.

At Bryn Mawr Dr. R. F. Brunel studied the preparation of diazomethane and chlor and brom ketones. He was assisted by three volunteer chemists.

At Ohio State University Dr. C. A. Boord worked on mustard gas, phenylchlorarsine, diphenylchlorarsine, and on the selenium and tellurium derivatives of mustard gas, which for a time threatened to displace mustard gas.

At Harvard University Dr. G. P. Baxter did much work on the physical constants of the war gases, especially their vapor pressures, thus supplying data that were essential for the proper use of these materials.

Dr. E. E. Reid, of Johns Hopkins University, who became a consulting chemist of the Bureau of Mines in May, 1917, helped greatly in interesting the chemists of the country in the work on noxious gases, and in having them submit organic preparations. He had charge of a group of investigators working on problems of organic chemistry at the university.

Dr. Reid Hunt, at Harvard University, with a staff of pharmacologists, investigated toxicological problems.

Dr. G. A. Hulett, head of the department of physical chemistry at Princeton University was sent abroad in April, 1917, by the Bureau of Mines as a member of a commission appointed by the National Research Council to gather data on technical war problems. He gave especial attention to the use of noxious gases in warfare, and brought back information that proved of immense value. After his return he organized a research group at Princeton, that studied the physical properties of charcoal. These studies brought out new facts regarding the absorption of gas by charcoal. Dr. Hulett also developed a novel method for the removal of iron oxide from glass sand by the use of phosgene. This reaction has other possible industrial applications.